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Irrigation Water Salt Concentration Influences on Sediment Removal by Ponds[1]

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ABSTRACT

Irrigation water salt concentration effects on sediment pond efficiency were investigated to demonstrate the necessity of considering the salt concentration in the irrigation waters when designing sediment retention ponds. The influence of dissolved salt was determined by adding concentrated $CaCl_2$ solutions to three ponds and then measuring electrical conductivities and sediment concentrations at the pond outlets. Increasing the salt concentration increased the sediment removal efficiencies when the retention time in the pond exceeded 1 hour or the inflow sediment concentration exceeded 500 ppm for the three soils studied. Adding salt to laboratory soil sample suspensions increased the settling rates for the two soils studied. That data indicate that the salt concentration in irrigation water is an important factor in determining sediment pond size and retention time. Using pond design criteria obtained from sediment ponds receiving water of a given salt concentration to design ponds that will receive water with a different salt concentration should include adjustments for salt concentration differences. A simple laboratory test is suggested to predict which soils will respond to irrigation water salt concentration changes that are likely to result in sediment pond efficiency changes.

Additional Index Words: **sediment control, irrigation return flow, flocculation, coagulation, water treatment.**

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IRRIGATION AND NATURAL RUNOFF waters can transport large quantities of sediment into rivers and streams (3, 6, 12). Problems associated with detached, transported and deposited sediments have stimulated increased interest in controlling sediment movement into streams, lakes and harbors. The importance of sediment in drainage waters has prompted further investigation into ways of decreasing soil loss from the land. On-farm and irrigation project sediment ponds and small reservoirs have been studied to determine sediment removal efficiency factors and design requirements[3] (2, 6). Sediment load, particle size, and flow rates are the initial information needed for sediment pond design and size (2, 7, 12). The next step is to determine other factors that influence sediment removal efficiency.

Sediment pond design is usually based on Stokes' law. The assumptions necessary for applying Stokes' law are: (i) particles are large enough not to be affected by Brownian movement, (ii) particles are rigid and smooth and maintain their size, shape, and individuality during settling, (iii) settling occurs without interference from other particles, and (iv) the Reynolds number does not exceed 10. Under these conditions, liquid viscosity is the only resistance to the falling particles.

These assumptions are not always completely satisfied for soil-water suspensions. Interactions between electrically charged soil particles in suspension change as the dissolved salt concentration in solution changes. Changes in the proportions of various cations can also change the stability of a soil suspension. Treating municipal waste water with various salts to change the specific ion concentration can cause colloidal particles that normally repell each other, to coagulate into larger particles which settle faster (5, 7).

Sediment pond data obtained in one area of southern Idaho[3] have been used for sediment pond design in other areas of the region (1) based on their textural class alone. These soils do vary however in their genetic background and chemical composition (8, 11). Differences in dissolved salt concentrations of the irrigation water and their effects on sediment pond design have also been ignored. The electrical conductivity of southern Idaho's irrigation waters range from 70 to 2,600 μmhos/cm over very short distances in some areas (4, 10). This study was conducted to determine the change in sediment removal efficiencies caused by changes in salt concentration in irrigation water.

MATERIALS AND METHODS

Field Study

Three sediment ponds that collected runoff water from row-cropped land irrigated with low total salt waters were selected for the field portion of the study. The first pond located southwest of Twin Falls, Idaho, collected runoff water from a 4 ha dry bean *(Phaseolus vulgaris)* field with a slope of 1% or less. The Portneuf silt loam soil (18% sand, 62% silt, and 20% clay) on this field is classified as a Durixerollic Calciorthid. It is a calcareous soil formed in loess deposits over basalt plains (8). The irrigation water had an electrical conductivity of 100–110 μmhos/cm. The second pond collected runoff from about 1 ha of a corn (*Zea mays* L.) field near Caldwell, Idaho, with a 1–3% slope on Vickery-Marsing silt loam (30% sand, 51% silt, and 19% clay) complex receiving irrigation water with an electrical conductivity of 160–170 μmhos/cm. These soils are predominantly Xerollic Durorthids which were formed in a thin wind deposited silt overlying unconsolidated sediments. It is a noncalcareous soil (11). The third pond collects water from a hop (*Humulus lupulus*) field on Greenleaf-Owyhee silt loam (23% sand, 51% silt, and 26% clay) complex with a 1–3% slope. These Xerollic Haplargids are noncalcareous and were formed in layered lacustrine and alluvium material that is overlain by thin loess deposits in places

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[3]F. L. Ballard. 1975. Analysis and design of settling basins for irrigation return flow. M.S. Thesis. Univ. of Idaho, Moscow, Idaho. 65p.

(11). The pond is northeast of Notus, Idaho, and collects water with an electrical conductivity of 72–80 μmhos/cm.

Sampling was started on each pond after the flow rate measured through an inlet flume into the pond had stabilized during a 24- to 48-hour irrigation set. Concentrated $CaCl_2$ solution, at a rate sufficient to increase the electrical conductivity to about 1,000 μmhos/cm at the pond outlet, was metered into the stream above the pond at a point where mixing was assured. The time required for the outlet electrical conductivity to reach 1,000 μmhos/cm was about twice the retention time of the pond. This salt concentration was maintained for an additional 0.5 hours, and then decreased at approximately 200 μmhos/cm increments at 0.5-hour intervals until the salt solution was stopped. Inlet and outlet samples (200 ml) were taken at 0.25-hour intervals from 0.5 hours before salt treatment was started until the salt concentration at the outlet was within 50 μmhos/cm of the original inlet electrical conductivity. Flow was measured through a trapezoidal flume into the bean pond and through Parshall flumes into the corn- and hop-field ponds.

The inlet and outlet water samples were taken into the laboratory, vacuum filtered through preweighed 0.45 μm filter papers, oven dried at 105° C, and the soil and filter paper were reweighed to determine sediment concentrations. Electrical conductivity was measured on the filtrate.

Laboratory Study

Portneuf silt loam and Greenleaf-Owyhee silt loam samples taken from the bean and hop fields, were wet-sieved through a 49 μm (300 mesh) sieve, and stock suspensions prepared. A concentrated salt solution containing NaCl, $MgCl_2$, and $CaCl_2$ with a 2:3:5 equivalent cation ratio, representative of the waters used to irrigate many soils in the study area, was prepared (4).

Two hundred ppm sediment suspensions were made by mixing appropriate stock suspension, and salt solution volumes for 5 min in soil dispersion cups and made up to 1,200 ml with distilled water in glass cylinders. The electrical conductivity of the final solution ranged from 20 to 2,000 μmhos/cm. The cylinders were inverted 20 times to mix the contents and then allowed to settle for 1, 2, 4, or 24 hours. The upper 0.25 m of suspension was decanted through a J-shaped tube at the predetermined time. Water entered the tube from above with minimal mixing during decanting as the water level dropped. About 800 ml of suspension sample was removed. The samples were vacuum filtered through preweighed 0.45 μm filters, dried at 105°C and reweighed to determine the average sediment concentration in the 0.25-m sample depth. The filtrate electrical conductivity was measured on each sample.

RESULTS

Field

Increasing salt concentration increases the sediment removal efficiency of sediment ponds (Fig. 1a, 1b, 1c). Outflow sediment concentration, Y, plotted against electrical conductivity, X, for two irrigations on each of three ponds gave relationships of the form $Y = A + BX^{-1/2}$ (Table 1). The equations in Table 1 correspond to the curves in Fig. 1a, 1b and 1c. The beanfield pond data show the effect of time when sediment concentrations are nearly the same. Increasing the salt concentrations has a greater relative effect for longer sediment pond retention times when the inflow sediment concentrations are nearly the same. The corn field pond data illustrate the dissolved salt concentration change effects at different sediment input rates. The greater the inflow sediment load, the greater the relative decrease in outflow sediment concentration for similar electrical conductivity increases and pond retention

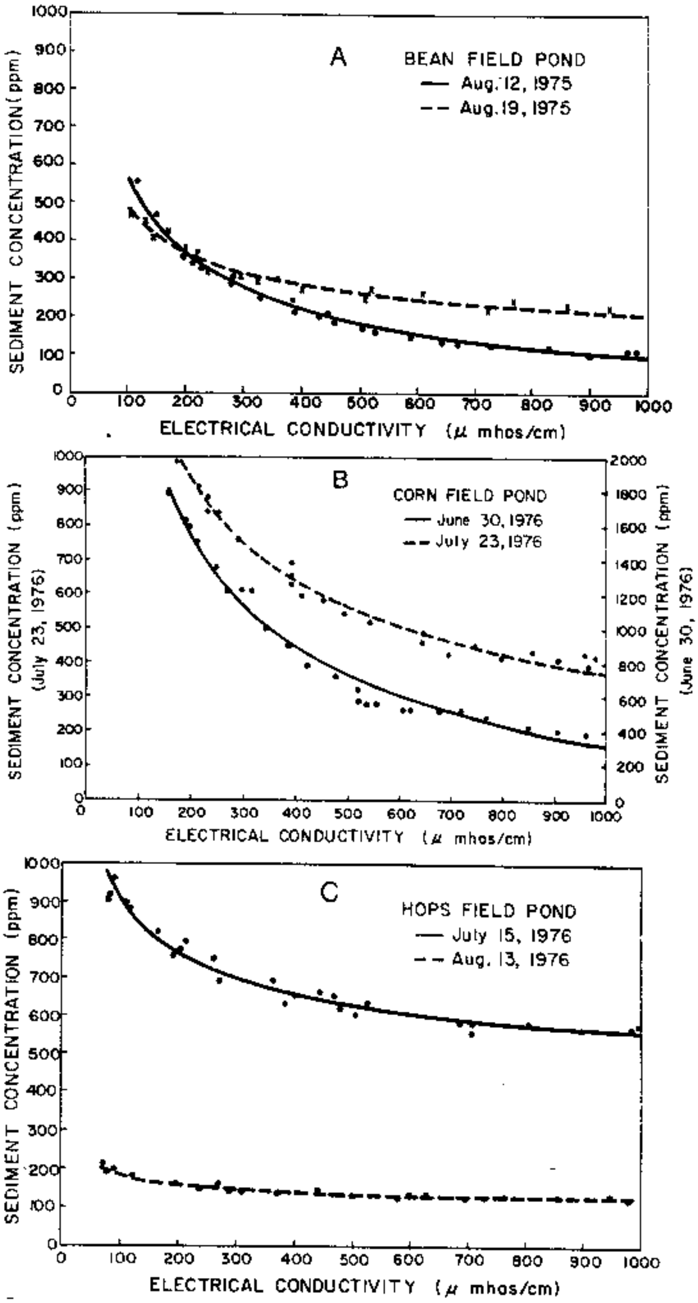

Fig. 1—(*A, B, C*) Outflow sediment concentration (ppm) as affected by electrical conductivity (μmhos/cm) changes resulting from $CaCl_2$ solution additions to irrigation runoff water for two irrigations on three soils.

times. The hop field pond data illustrate the relatively small effect of salt concentration increases for low inflow sediment concentrations coupled with short retention times (13 Aug. 1976). Combining the information from the three ponds shows that the electrical conductivity effect on sediment pond efficiency will increase as either the inflow sediment load or pond retention time increases.

The sediment pond efficiency for the flow volumes and sediment concentrations as affected by electrical conductivity changes can be calculated by:

$$\text{pond efficiency} = 1 - (Y/\text{Inflow sediment concentration})$$

Table 1—Flow rates, initial electrical conductivities, inflow sediment, concentration, retention times, electrical conductivity-outflow sediment relationships, and R^2 values for two irrigations in three sediment ponds.

	Average flow	Initial electrical conductivity	Inflow sediment concentration	Retention time	Electrical conductivity-sediment concentration relationship†	R^2
	m^3/sec	$EC \times 10^{-6}$	ppm	hours		
			Bean field			
12 Aug. 1975	0.0091 ± 0.0005	100	2,145 ± 98	2.5	$Y = -124 + 6923X^{-1/2}$	0.98
19 Aug. 1975	0.0144 ± 0.0006	110	1,418 ± 177	1.5	$Y = 77 + 4117X^{-1/2}$	0.86
			Corn field			
30 June 1976	0.0076 ± 0.0001	160	5,342 ± 738	0.7	$Y = -689 + 31550X^{-1/2}$	0.96
23 July 1976	0.0074 ± 0.0003	170	2,959 ± 373	0.7	$Y = -134 + 15236X^{-1/2}$	0.86
			Hop field			
15 July 1976	0.0105 ± 0.0003	80	1,885 ± 221	1.0	$Y = 400 + 5091X^{-1/2}$	0.92
13 Aug. 1976	0.0139 ± 0.0003	72	361 ± 42	0.8	$Y = 95 + 929X^{-1/2}$	0.95

† Y = sediment concentration of pond discharge water (ppm). X = electrical conductivity of discharge water (μmhos).

Table 2—Sediment concentrations above 0.25 m in laboratory cylinders as affected by time and electrical conductivity for the bean field and hop field soils and the relationship R^2 values.

Soil		Settling time: 1 hour	2 hours	4 hours	24 hours
Bean field soil	‡	$Y = 71 + 1226X^{-1/2}$	$Y = 24 + 1436X^{-1/2}$	$Y = -8 + 1588X^{-1/2}$	$Y = -40 + 1679X^{-1/2}$
R^2		0.91	0.95	0.95	0.97
Hop field soil		$Y = 82 + 47X^{-1/2}$	$Y = 13 + 3487X^{-1/2}$	$Y = -70 + 3956X^{-1/2}$	$Y = -59 + 2026X^{-1/2}$
R^2		0.74	0.90	0.92	0.88

‡ Y = Average sediment concentration (ppm) above 0.25 m. X = Electrical conductivity of solution (μmhos).

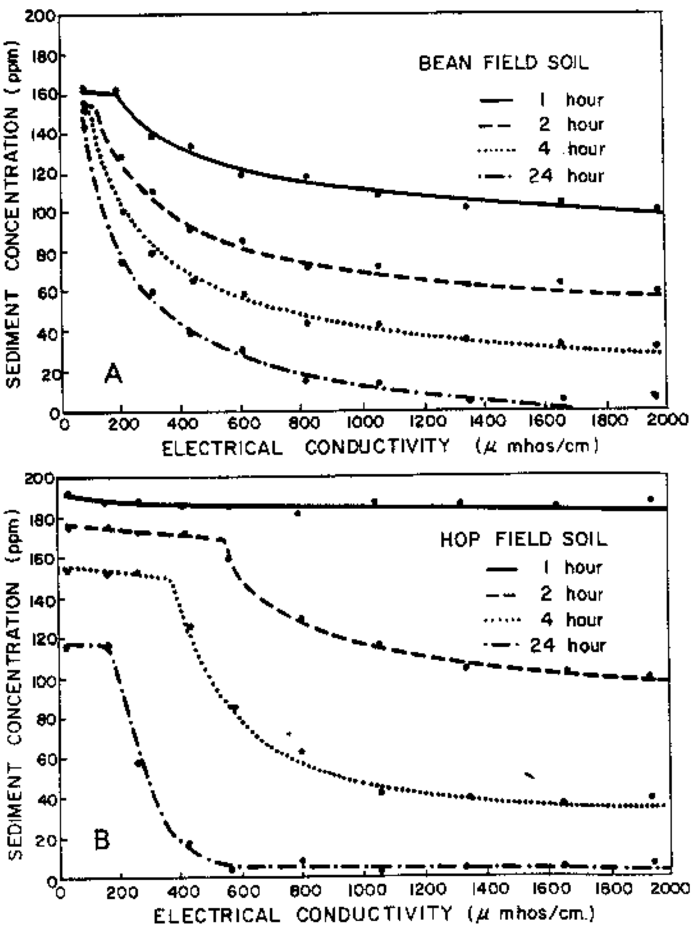

Fig. 2—(A, B) Suspended solids concentration (ppm) as affected by time and solution electrical conductivity for the bean field and hop field soils.

where Y is the outflow sediment concentration from the electrical conductivity vs. sediment concentration relationships (Table 1). As an example, on 30 June 1976, for the corn field pond the initial sediment pond efficiency with an electrical conductivity of 160 μmhos/cm was 66%. When the electrical conductivity was raised to 500 μmhos/cm the efficiency was increased to 87% and at an electrical conductivity of 1,000 μmhos/cm the efficiency was 94%.

Laboratory

The electrical conductivity vs. suspended solid concentration curves (Fig. 1A and 2A) and the mathematical relationships (Tables 1 and 2) for the bean field sediment pond and the laboratory settling tests for that soil were of the same form. The hops field soil had the same general shape in the laboratory as in the field but the curved portion of the plot was displaced to the right (Fig. 2B). It appeared that a seeding condition was required for this soil. When the 2-hour samples with higher electrical conductivities were disturbed or moved during sampling the sediment could visually be seen to coagulate. This delay in coagulation is indicated by the flat portions on several of the curves and the horizontal displacement was probably a time displacement effect caused by failure of the clay to coagulate rapidly. The flat portion of the curves are not represented in the mathematical relationship of Table 2. This flat portion was not observed in the field where there was continuous motion in the ponds.

DISCUSSION

Many soils of the productive Snake River Plain area of the Columbia Plateau are wind deposited silt loams with very similar textures (10, 11). Because of these similarities, data obtained for sediment pond efficiency and design in one locale has been applied in neighboring areas without considering the salt concentration in the irrigation water. This may result in errors in estimating pond efficiency because the salt concentration in irrigation waters of southern Idaho range from an electrical conductivity of 70–2,600 μmhos/cm (4, 9, 10).

If the sediment pond retention time is < 1 hour and the incoming sediment load is < 500 ppm, salt concentrations can probably be ignored. However, for longer retention times or higher sediment loads, dissolved salt concentration will likely have an effect on sediment removal efficiency.

The problem has occurred where sediment pond data obtained from land irrigated with waters with 550 μmhos/cm conductivity[3] (4) have been applied (1) to areas being irrigated with waters with electrical conductivities of < 100 μmhos/cm. Using the 30 June 1976 data from the corn field as an example, a sediment pond with inflow water containing 5,300 ppm sediment would have been predicted to contain 700 ppm sediment in the outflow rather than the 1,830 ppm measured if electrical conductivity was not considered (Fig. 1B). This represents a predicted pond efficiency of 87% whereas the actual efficiency was 66%. The pond size would have to be 2.6 times larger than would have been estimated from the saltier water to obtain the predicted 87% sediment removal for these conditions. Likewise, ponds designed for saltier water would be larger than required to meet a given removal efficiency, thus using more space and costing more to build than necessary.

The simple salt concentration test used in the laboratory part of this study is intended as a means of identifying those soil-water-salt concentration combinations in sediment ponds that will likely respond to salt concentration changes. The data shown here is not intended as sediment pond design input, but rather to show what may be expected with changes in salt concentrations. It should be remembered that the mathematical relationships given for the ponds were obtained from a chemically disturbed system that may not have been at equilibrium. Additional information is needed to develop quantitative relationships for sediment pond design which includes dissolved salt considerations.

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